NEW ELECTRON BEAM DIAGNOSTICS IN THE FLASH DUMP LINE

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Abstract

Additional beam diagnostics has been installed in the dump line at FLASH in 2009. Its purpose is to prevent damage by long high current electron beam pulses, as happened in autumn 2008, when a vacuum leak occurred near the dump vacuum window. Beam position monitors (BPM), scintillator-based loss monitors and temperature sensors were installed so-far. Additional BPMs and loss monitors have meanwhile been installed. These include a magnetic coupled BPM placed after the vacuum window. Magnetic loops are used in order to prevent the influence of the ions on the pick-up signals. 4 ionization chambers, consisting of air-filled tubes, and 4 glass fibers have been installed parallel to the vacuum pipe, along the last 2 m of the beam pipe. Beam halo monitors were installed next to the magnetic BPM. These consist of 4 diamond and 4 sapphire sensors operating as solid state ionization chambers. The halo monitors are very sensitive to charged particles crossing the detectors. These additional diagnostic monitors have been commissioned in autumn 2009, when they have contributed to the successful run of long pulses with 3 to 9 mA current and up to 800 µs length. Their performance is summarized in this paper.

INTRODUCTION

FLASH (Free electron LASer in Hamburg) [1] is at the same time a user and a test facility. A laser light tuneable in the range 40 – 6.5 nm is produced for several user beam lines. During special studies periods, various experiments are scheduled, in order to make tests for various accelerator projects, in particular for the European XFEL (X-ray Free Electron Laser) [2] and the ILC [3] (International Linear Collider) study. These have similarities with FLASH, in particular the superconducting technology used for beam acceleration. Also, they all plan to use long bunch trains.

The long bunch trains at FLASH have to be safely sent into the dump at the end of the linac. Beam loss monitors (BLM) and charge monitors are primarily used for the machine protection. This paper shows the limitations of the dump diagnostics used so far, describes the modifications made and summarizes the results of the initial commissioning of the new devices.

The FLASH Facility

A schematic view of the FLASH linac is shown in Figure 1 as of September 2009. A photo-electric gun generates pulses of electron bunches with an energy of about 5 MeV. These are accelerated to up to 1 GeV by 6 accelerating cryo-modules, each containing 8 TESLA superconducting cavities. Two magnetic bunch compressors reduce the bunch length to less than 100 fs. A collimator section lowers the radiation losses in the undulators, by reducing the parasitic transported dark current. The beam properties are measured in two matching sections. While passing through the 30 m long undulators, the electron bunches produce FEL (Free Electron Laser) light through the SASE (Self-Amplified Spontaneous Emission) effect. The electrons are then sent to the beam dump, designed for about 100 kW power of a 2 GeV beam [4]. The FEL light goes to one of the user beam lines. A bypass line is used during test and commissioning periods in order to protect the undulators.

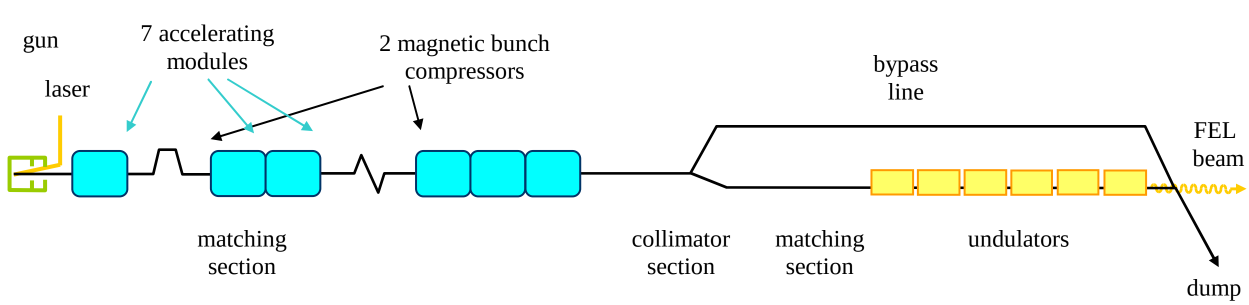

Figure 1 Schematic overview of FLASH (status 2009).

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Requirements of the Beam Dump for FLASH

Long pulses with up to 800 bunches with a frequency of 100 kHz – 1 MHz and a charge of 1 nC per bunch are often required during user runs. Also some tests for the XFEL or the ILC require long pulses. Particularly demanding is the so-called 9 mA experiment, whose aim is to accelerate stably 800 µs pulses with 3 nC bunches and a repetition frequency of 3 MHz [5].

Typical FLASH parameters relevant for operation with long bunch trains are summarized in Table tab-flash.

Table tab-flash Typical FLASH parameters for user operation and for the 9 mA experiment (status 2009)

Parameter	**Typical Values**	**9 mA run (goal)**
Bunch charge	1 nC	3 nC
Bunch repetition frequency	0.1 – 1 MHz	3 MHz
Pulse repetition frequency	5 Hz	5 Hz
Max. pulse length	800 µs	800 µs
Energy	450 MeV – 1 GeV	max

Both the charge and the bunch repetition frequency are increased for 9 mA experiment with respect to the normal user operation, in order to approach the high beam current planned for the ILC.

FLASH Dump Line

The FLASH dump line – status Summer 2009 - is schematically shown in Figure 2. The electrons coming from the bypass and from the SASE undulators are directed towards the dump by one of two dipole magnets. Several corrector magnets and quadrupoles control the beam trajectory and size. An electrically modified sextupole magnet (rotator) distributes the beam in a circular manner on the dump and thus lowers the average power density impact. Several BPMs (beam position monitors) measure the beam position. A toroid reads the beam charge. An OTR (optical transition radiation) screen can be driven into the beam to check the beam size. BLMs (beam loss monitors) are distributed along the section. They are made of a scintillator material protected from light coming from the tunnel area. Their light is then transformed into a current by photomultipliers.

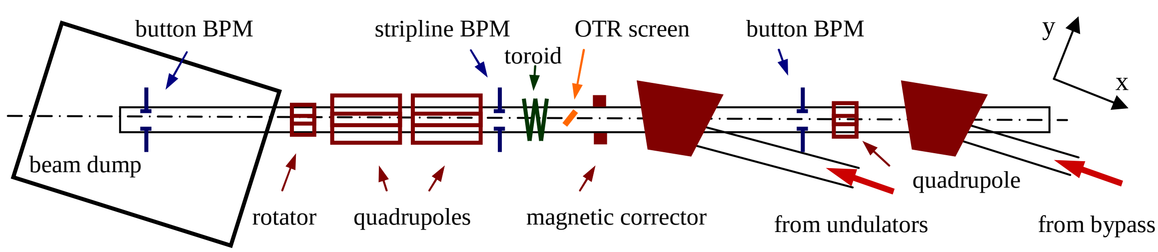

Figure 2 Schematic view of the dump beam-line at FLASH (status Summer 2009). The line has an angle to the horizontal of 19 deg. The beam comes from main beam-line or the bypass (right in this figure). Several BLM distributed along the line are not shown.

For runs with long pulses this existing diagnostics seemed to be sufficient. However in Autumn 2008, during a 9 mA experiment, a vacuum leak occurred near the window at the end of the beam pipe caused by a pulse with 550 bunches with a charge per bunch of 2.5 nC, a repetition frequency of 1 MHz and an energy of 890 MeV. Also the last BPM situated just in front of the vacuum window seemed to be damaged by radiation. This showed that the dump diagnostics system in the dump beam line has to be re-designed.

DUMP LINE MODIFICATIONS

Several new systems have been built and installed in FLASH in Summer 2009. Apart from a new button-type BPM installed between the quadrupoles, the modifications regard the last 2 m of beam line. This sections is shown in Figure 3. The button BPM previously placed just before the dump vacuum window (compare to Figure 2), has been moved upstream. Several pipes can be seen around the beam pipe: 4 of them host glass fibres together with Cerenkov fibres* and 4 larger ones are used to accommodate ionization chambers. After the vacuum window, a magnetic coupled BPM and a BHM (beam halo monitor) have been installed. The new systems were commissioned in September 2009, during the 2nd 9 mA run. They are described in this section.

* Not yet commissioned, therefore not described in this paper

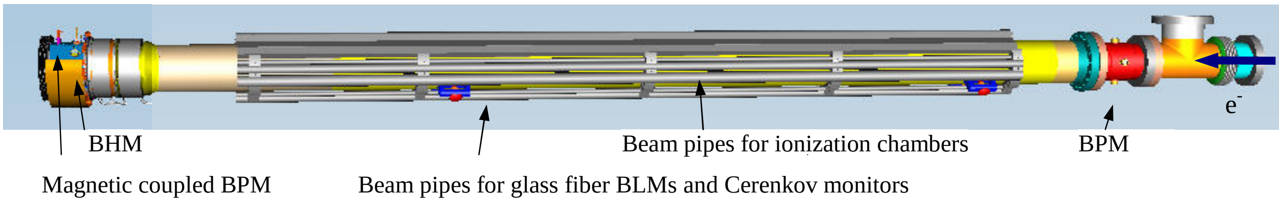

Figure 3 Drawing of the modified vacuum chamber after last magnet in Figure 2. The beam comes from the right.

Magnetic coupled BPM

A BPM has been added after the vacuum window, in an area filled with dry Nitrogen N_2. Since the signal of button-type pickups would be affected by ions produced by electrons in the gas, it was decided to use the magnetic field of the bunches for generating a position signal. For this, 4 wire loops have been designed, which are placed parallel to the beam for optimal coupling to the magnetic field of the charged particles only, as shown in Figure 4 [6].

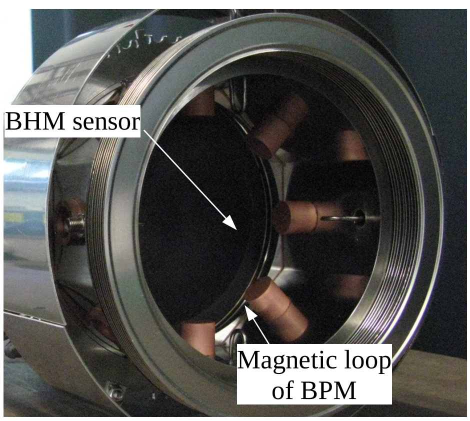

Figure 4 Beam pipe section after vacuum window, including magnetic coupled BPM and BHM.

The signal from each loop is low-pass filtered below 200 MHz to cut high frequency components of the compressed beam, as it is done for button BPMs in the other parts of FLASH. The processing electronics is based on the AM/PM principle [7].

The BPM signals have been analytically estimated and simulated with the CST code [8]. The signals from all pickups have been measured during the 9 mA run in September 2009. The comparison of one such signal to the simulation is shown in Figure 5. The agreement is good in the positive part of the signal. The differences in the negative part need more investigation.

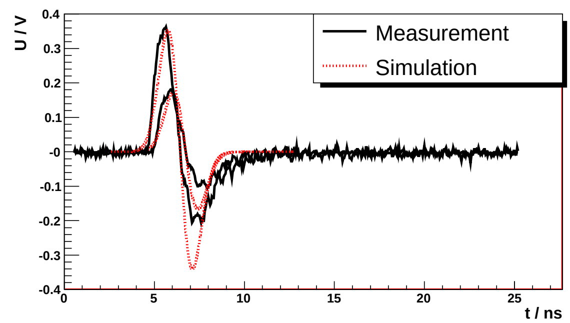

Figure 5 The signal voltage as a function of time from the vertical wires of the BPM. The amplitudes are corrected for the attenuation of the cables and low-pass filter.

Glass fibres

Along the last 2 m before the dump (see Figure 3), four BLMs consisting of glass fibres read out with photomultipliers have been installed around the pipe. These collect thus the beam losses which occur at each side of the beam pipe.

Ionization chambers

4 ionization chambers have also been placed along the last 2 m of beam pipe. These are air filled 3/8” Heliax HF cables. The ions created by the ionization radiation produced by beam losses are measured. The electronics has a large dynamic range, from 10^{-4} to 10^{4} µA.

Beam halo monitors (BHM)

The BHM consists of four 500 µm thick artificial mono-crystalline sapphire sensors and four 300 µm thick pCVD diamond sensors with an area of 12×12 mm^2 placed inside caps alternatively around the beam pipe, and next to the magnetic coupled BPM, as seen in Figure 4 [9]. These sensors operate like solid state ionization chambers. The sensors have to withstand high radiation doses.

In beam tests, the signals from the sensors have been seen to increase while the beam approached each sensor. The diamond sensors are more sensitive than the sapphires.

BEAM MEASUREMENTS

The new diagnostics systems described in the previous section have been commissioned during the 9 mA experiment in Autumn 2009. Figures 6-9 show 10 successive beam pulses as seen on various devices. The beam repetition frequency was 3 MHz, however only every 3rd was sampled by the ADCs for each device.

Figure 6 shows the bunch charge along each pulse, about 2.7 nC per bunch. There is a stronger charge variation at the beginning of the pulses which disappears towards the tail of the train. There are 200 bunches per pulse except for one pulse where the machine protection system has reduced the train.

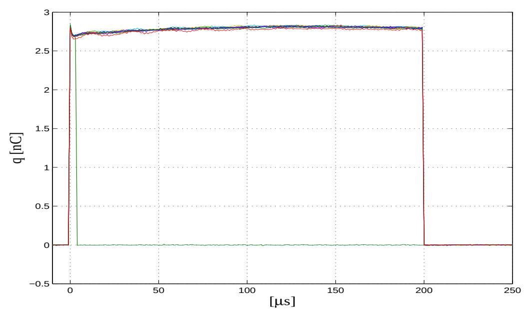

Figure 6 Bunch charge of 10 subsequent pulses.

Figure 7 shows that each of the 10 pulses had an offset from the beam-pipe axis of 2 to 5 mm in the horizontal direction and 4-5 mm in the vertical plane at the dump. Note that at the time of measuring, a slope calibration error may have been present.

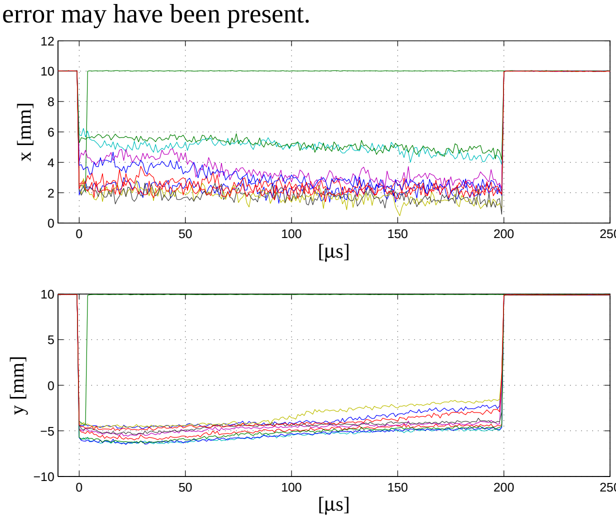

Figure 7 Bunch offset of 10 pulses, corresponding to Figure 6, as measured at the magnetic coupled BPM.

The ionizations chambers showed the signals from Figure 8. They measure integrated losses along the pulse, including losses from dark current which is transported along the linac. The signals are delayed with respect to the bunch arrival time due to the slow speed of the ions. The ionization chambers have a large dynamic range.

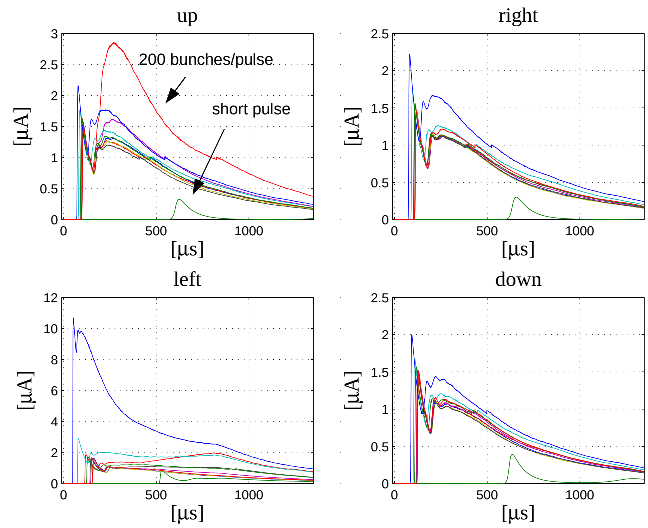

Figure 8 Signals from ionizations chambers corresponding to previous 2 figures. (Please note the different horizontal scale than for toroid, BHM and BPM plots.)

The signals from the beam halo monitors are shown in Figure 9. The up, right, down and left signals (in the beam direction) are from the sapphire sensors, while the remaining ones are from diamond sensors. One can see that the diamond sensors are more sensitive than the sapphire ones. In this case the losses were very small. The glass fibers BLMs placed along the 2 m just before the BHMs did not show any signal. In other cases with large losses (largely off-centered beam), the diamond sensors saturated while the sapphire ones showed a good signal. Therefore using the two types of sensor increases the dynamic range of the monitor.

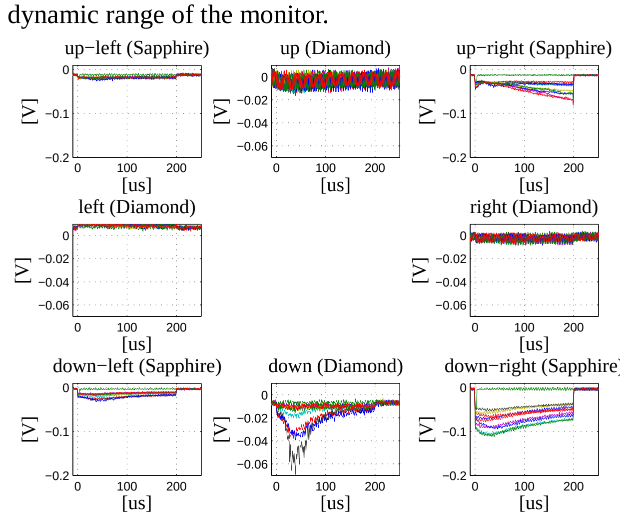

Figure 9 Signals from BHM sensors for 10 pulses corresponding to previous 3 figures. The up-right, down-right, up-left and down-left (in beam direction) sensors are diamonds, while the up, down, left and right signals are from sapphire sensors. Please note the different vertical scale.

CONCLUSION AND OUTLOOK

The additional diagnostics installed in the FLASH dump line has contributed to the successful 9 mA run in Autumn 2009. The various monitor types are complementary to each other and except for the transverse beam profile give a rather complete picture of the way the beam is dumped.

During the 9mA experimental run, pulses with 3 MHz bunch repetition frequency, 2 nC charge per bunch, a pulse length of 800 µs and an energy of 800 MeV have been achieved. A pulse length of 600 µs has been reached with 3 nC bunches, a record up to now.

After the 2 week long 9 mA run, the linac has been upgraded. The main changes are the installation of a new cryo-module, enabling a maximum energy of 1.2 GeV, the installation of a 3rd harmonic cryo-module in order to linearize the energy along the bunch, important for a more homogenous bunch distribution in the compression process and of a undulator section for a so-called seeding experiment. The pulses have now a frequency of 10 Hz, instead of 5 Hz before the upgrade. The commissioning of the linac is on-going.

Further investigations of the diagnostics installed in the FLASH dump line are going to be made during the current commissioning period as well as during further beam studies periods. Particularly the magnetic BPM and the BHMs will be studied in order to answer questions such as BPM constant and linear region, life time of BHM sensor etc.

Similar diagnostics is considered for installation in FLASH II, an extension of the current facility, and in the XFEL.

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